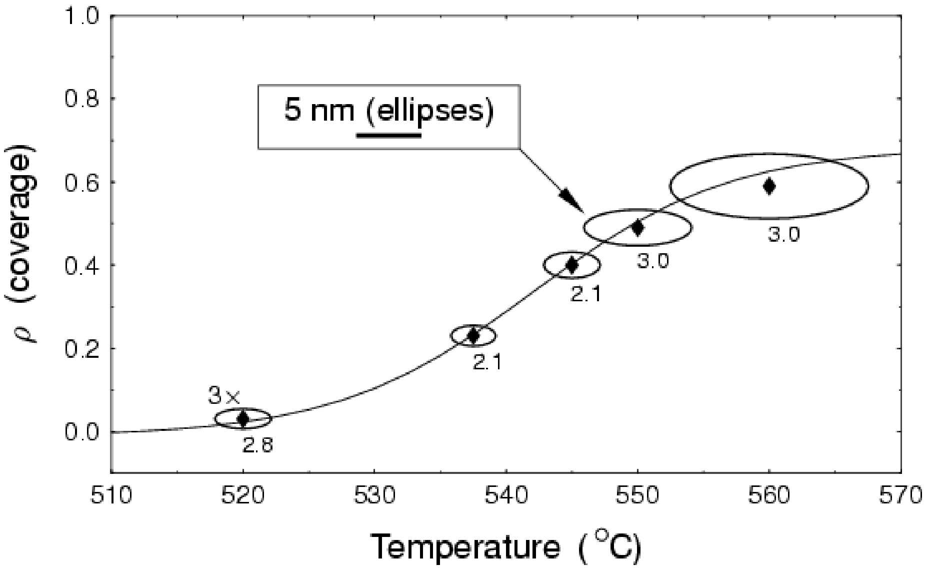
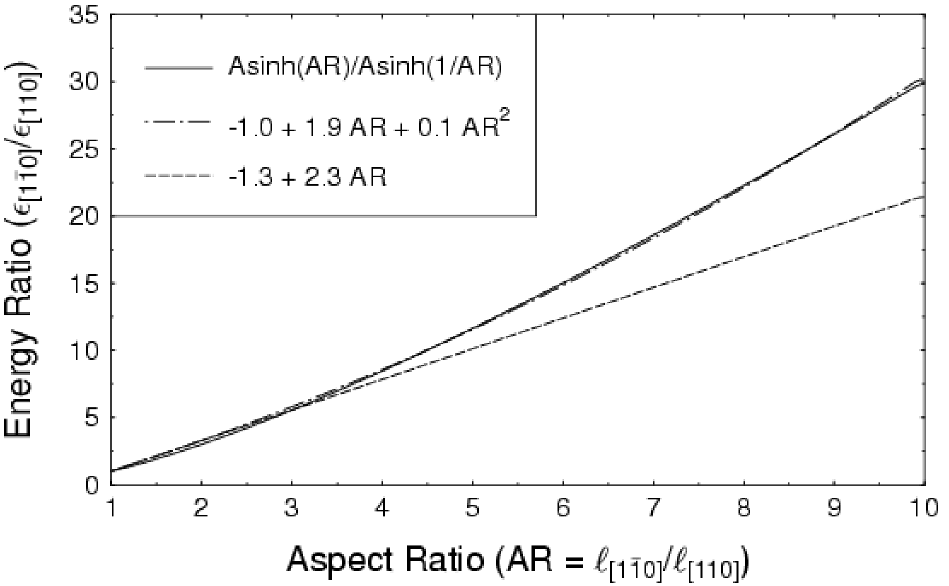
Tunable Concentration and Geometry for Self-Assembled Nanostructures





Concentration and lateral geometry of self-assembled 2D GaAs islands on the GaAs(001) surface change with temperature.

Step energy cost ratio associated with forming a 2D island within 2D Ising model and for different island geometries.

<u>Discovery Across the Frontier of Science, Connected to Innovation</u>

Origin of Spin Relaxation on Nanometer Scale

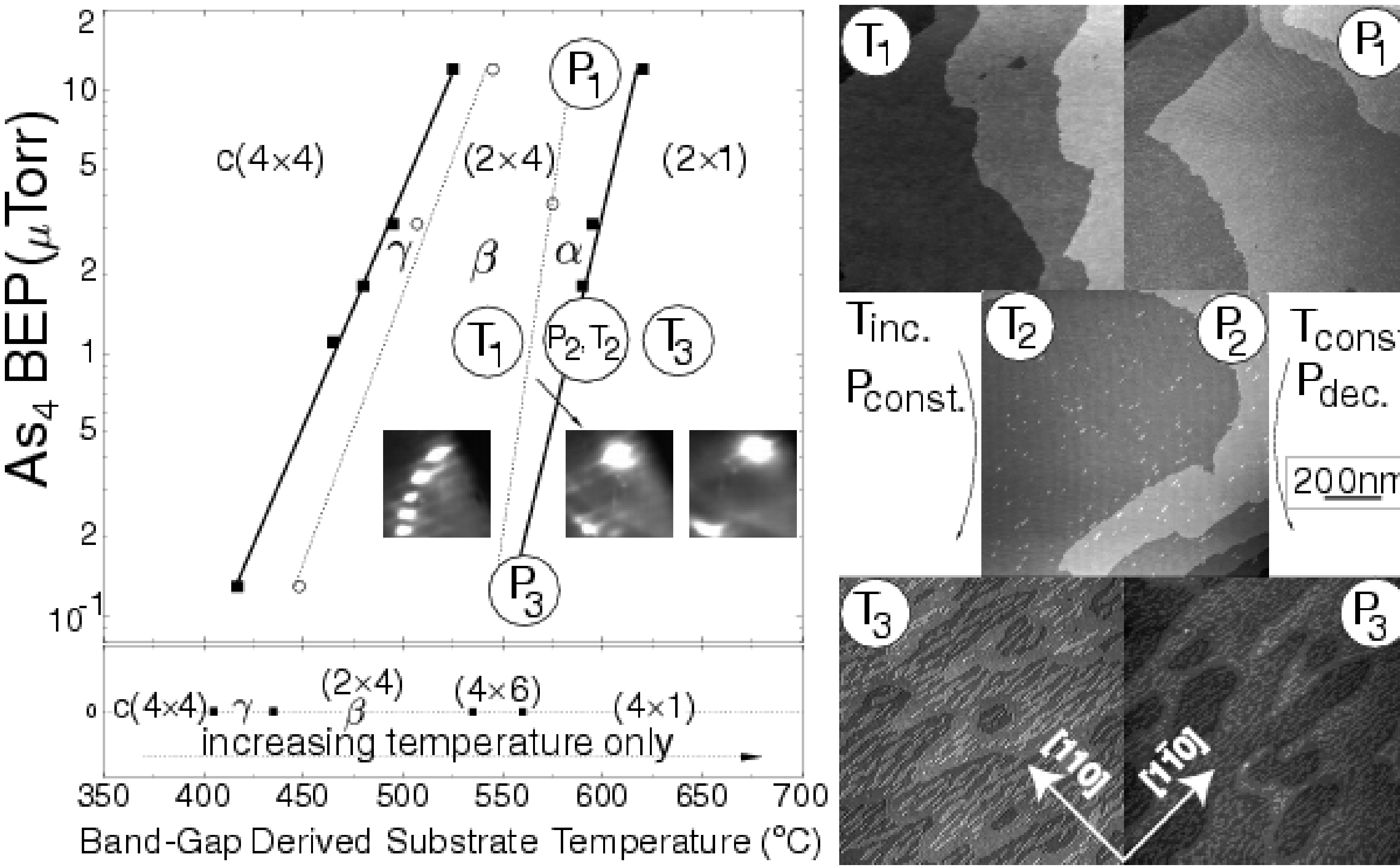
P. M. Thibado, Vince LaBella, Laurent Bellaiche, and Lin Oliver

U. Arkansas, Fayetteville; DMR-0102755 (Focused Research Group).

By placing a ferromagnetic metal on a semiconductor (versus a normal metal) it may be possible to utilize the spin of the electron (i.e., its magnetic moment) to make a new class of electronic devices. To make this a reality, one must preserve the direction of the electron's spin across the interface. One concern is that roughness at the ferromagnetic metal-semiconductor interface destroys the coherent spin transfer process. In order to test the effect an island at the interface has on the spin injection process we have developed a growth algorithm that allows us to reproducibly create islands with any concentration and geometry. In fact, we discovered that these islands spontaneously form on the surface of GaAs without growing any material [Phys. Rev. Lett. **84**, 4152 (2000)], so we can tune their physical properties simply by heating the substrate and controlling the arsenic pressure [J. Vac. Sci. Technol. **B 19**, 1640 (2001)], as shown in the left panel. Furthermore, we developed a theoretical understanding of the phenomenon that allows one to extract the energy costs for forming the 2D islands simply by looking at the geometry of the island, as shown in the right panel.

Our next step is to use our local spin injection probability detector to quantify the role these structures play in the spin-injection process. Without a detailed microscopic understanding of which atomic-scale features promote and demote the spin-injection process it is left to chance that these next generation devices will reach the market.

Tunable Concentration and Geometry for Self-Assembled Nanostructures



A recipe for producing a specific concentration and lateral geometry of self-assembled 2D GaAs islands on the GaAs(001) as a function of growth parameters and electron diffraction patterns.

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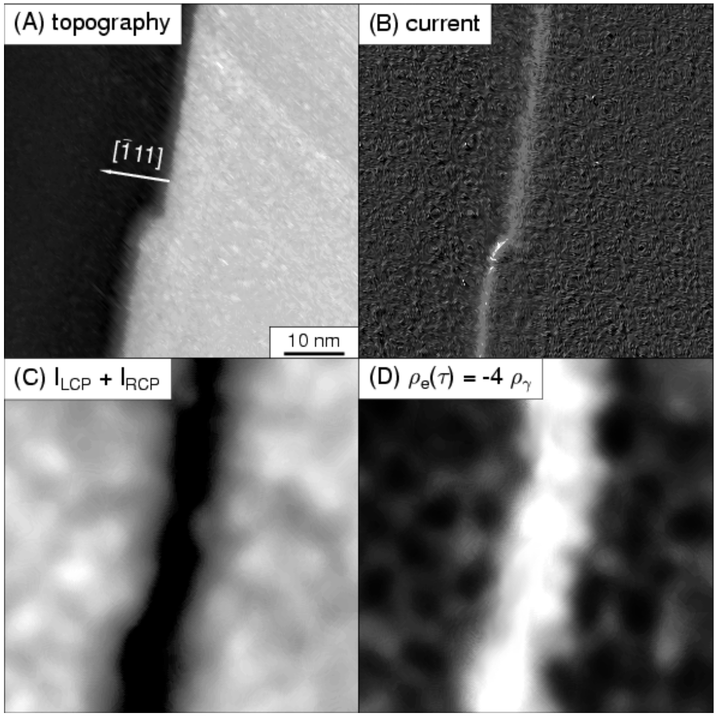
The ability to preserve the electron's spin orientation (i.e., the direction of its magnetic moment) across an interface is critical for the development of the next generation electronic devices coined spintronics. In order to test the effect an island at the interface between a ferromagnetic metal and a semiconductor has on the spin injection process we have developed a growth algorithm that allows us to tune the concentration and geometry of GaAs islands.

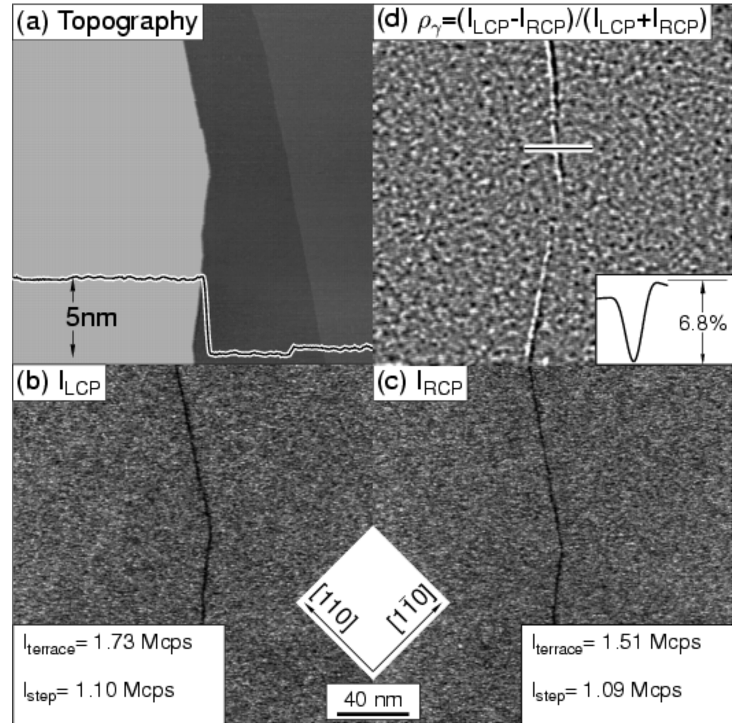
Now anyone with a standard growth chamber equipped only with electron diffraction can create these structures [Appl. Phys. Lett. **79**, 3065 (2001)]. The vast majority of growth chambers have electron diffraction, however, only a small minority have access to an ultra-high vacuum connection to a scanning tunneling microscope.

Our next step is to use our local spin injection probability detector to quantify the role these structure play in that process. Without a detailed microscopic understanding of which atomic-scale features promote and demote the spin-injection process it is left to chance that these next generation devices will reach the market.

Local Spin-Injection Probability from Ferromagnetic Metal to a Semiconductor



Spin-injection study using single crystal Ni[110] wire. Here we get a large spin-injection probability on the terrace and show that the 5nm step significantly disrupts the process.



Spin-injection study using poly-crystalline Ni wire. Here we show similar results to the single crystal wire.

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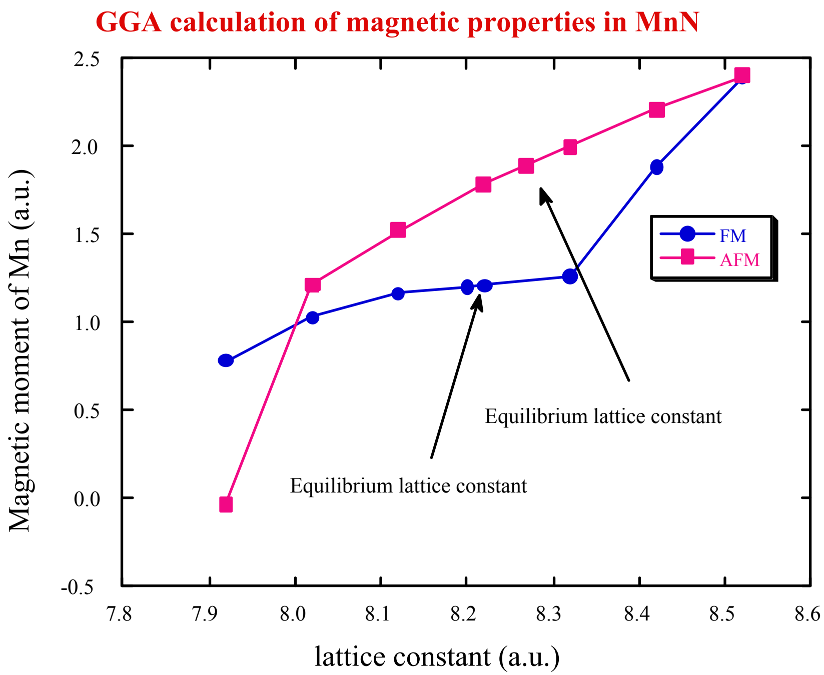
We were the first to develop a technique that allows us to measure the role nanoscale features have on the spin-injection process [Science 292, 1518 (2001)]. This tool makes it possible to show which atomic-scale defects effect the spin-injection process and maybe more importantly those defects that do not.

Our next step is to use our local spin-injection probability detector to quantify the role the 2D GaAs island structure play in the process. Without a detailed microscopic understanding of which atomic-scale features promote and demote the spin-injection process it is left to chance that these next generation devices will reach the market.

Theoretical Prediction of the Magnetic Properties of MnN



Using the GGA first-principles techniques, we compared the magnetic properties of zinc-blende MnN in a ferromagnetic (FM) state and in an antiferromagnetic (AFM) state. Unlike the commonly used LDA technique, GGA predicts the correct ground-state (i.e., AFM). One important finding is that the magnetic moment goes abruptly to zero for AFM-MnN (i.e., it becomes paramagnetic). The "Equilibrium lattice constant" label indicates the lowest energy configuration.

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The ability to preserve the electron's spin orientation (i.e., the direction of its magnetic moment) across an interface is critical for the development of the next generation electronic devices coined spintronics. To achieve this we must theoretically understand what controls the spin-injection and spin-transport properties of III-V semiconductors when spins are added from a ferromagnetic metal.

Our first effort toward this goal was to team up with Su-Huai Wei of NREL to model the effect of the electron's spin on total energy calculations. After his visit to Arkansas last summer, it appeared the best approach was to first put the spins in via making MnAs instead of GaAs.

Using two different first-principles techniques (LDA vs. GGA), we compared the magnetic properties of MnN and MnAs in their paramagnetic (PM), ferromagnetic (FM) and antiferromagnetic (AFM) zinc-blende structures. Unlike the commonly used LDA technique, GGA predicts the right ground-state (i.e., AFM). One important finding is that AFM-MnAs has a much larger magnetic moment than AFM-MnN, even though MnAs and MnN are both III-V semiconductors. This surprising result can be understood in term of atomic orbital energies and hybridization between Mn-d orbitals and anion-p orbitals. With this successful calculation complete we are now able to study GaAs by incrementally replacing Mn with Ga.

A Diverse and Internationally Competitive Scientific Workforce

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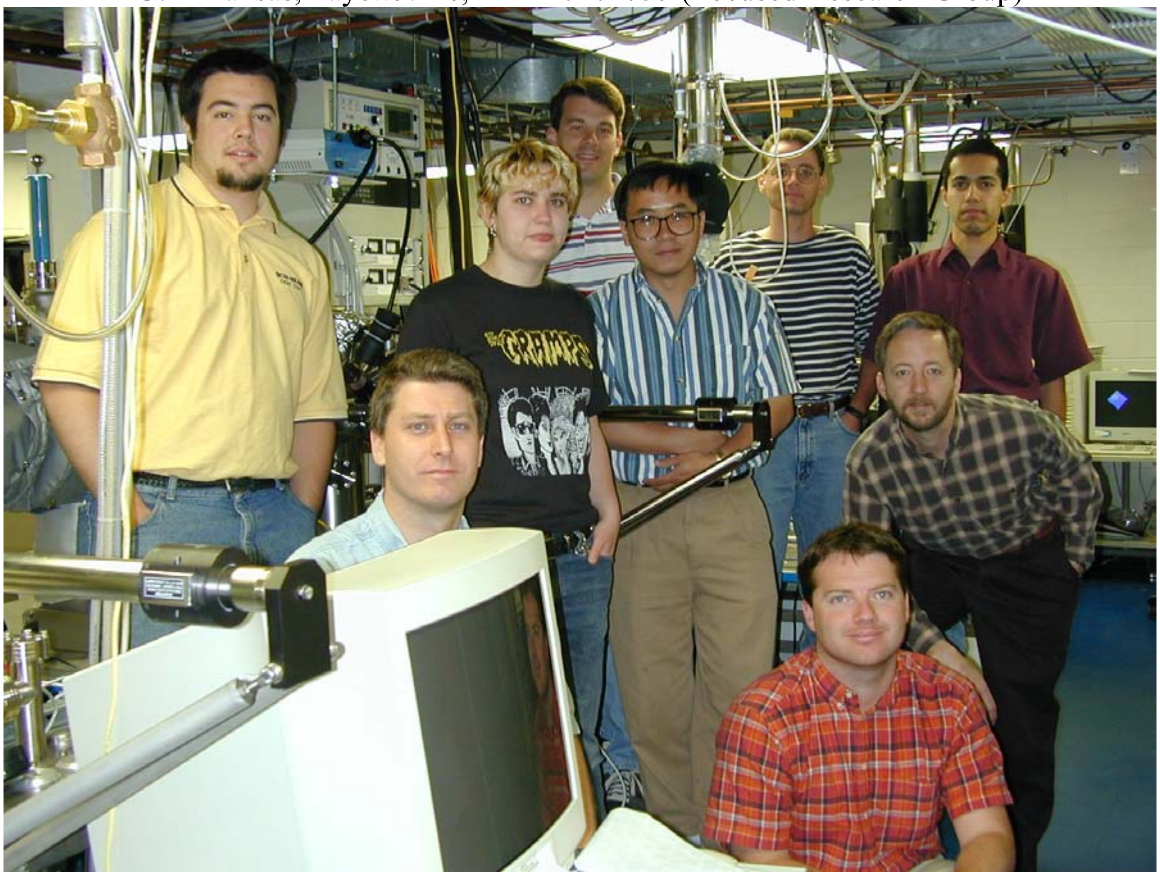

Back Row: Dr. Vince LaBella (Research Assistant Professor) is from upstate New York and brings significant experimental technical skill and unique cultural perspective. Dr. Laurent Bellaiche (Assistant Professor) is a Frenchman and brings significant theoretical technical skill. Mr. Shahram Seyed Mohammadi (Ph.D. Candidate) is from Iran.

Middle Row: Mr. Jason LaBella (REU student from Rose-Hulman) is from Indiana and is the cousin of Dr. LaBella. Ms. Robin Gold (REU student from Reed College) is from Oregon. Mr. Zhao Ding (Ph.D. Candidate) is from the mountainous region of China, and hopes someday to go back to his community and build a semiconductor research program. Dr. Lin Oliver (Associate Professor) is originally from West Virginia and brings optical expertise to the group.

Front Row: Dr. Paul Thibado (Associate Professor) is originally from Wisconsin and brings surface science expertise to the group. Dr. Daniel Bullock (Post-Doc) is a native Arkansan, and recently finished his Ph.D. with Thibado. Daniel was the first member of his family to attend college, and now he is interviewing for a faculty position at our Little Rock campus.

Well-Prepared Citizens

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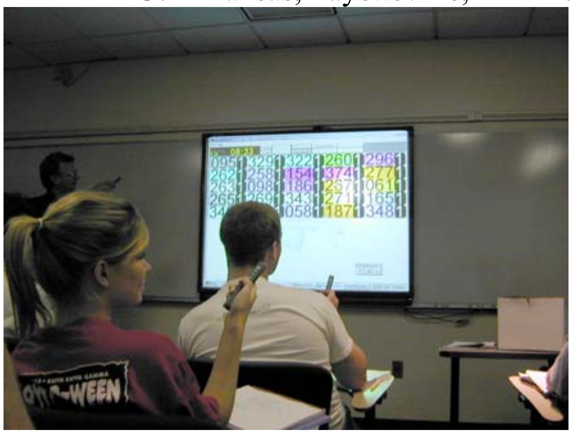
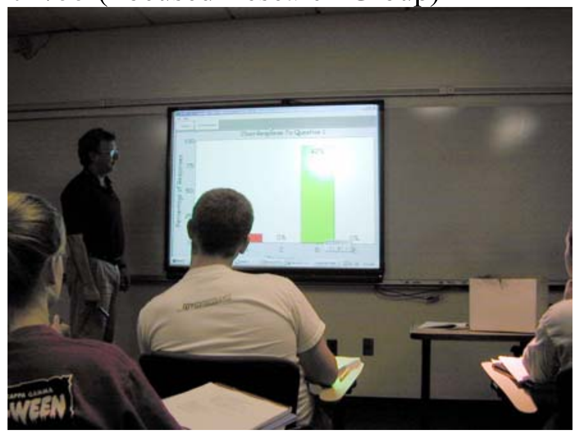


Question



Response

We believe the average American should have a basic understanding of Physics and of what Physicists do for a living. Our largest group of citizens we can address is in our freshmen level physics courses. We also believe that the way in which physics is traditionally taught, the majority of students cannot follow the material. By not following along, they lose interest and consequently do not appreciate the contribution physics has made to society. Thus, we have put a significant effort into making sure all of our students attend class and that they fully understand what is being taught to them.

The instructor mandates attendance in algebra-based college physics course. Students use individual remote control units (similar to your TVs) to answer questions throughout the lecture. Students are asked a question (left panel) and each answers with their own remote (tethered to their student ID number for grading purposes). Instantly a histogram shows the understanding or lack of understanding to the entire class. Concepts gotten by the majority are skipped over, so more time can be given to the more difficult material. Students are not only coming to class, but they are also engaged, asking questions, and doing significantly better on the exams.

These students are our future doctors, lawyers, and politicians. It is critical that they understand what physics is about, why it is important, and how it helps them live a better life. By using the remotes, we not only force them to come to class and pay attention, but the instructor quickly identifies what the students do not understand. Thereby, allowing immediate adjustments to be made to the lecture. Normally, the instructor learns the students did not understand a topic, only after they do poorly on a midterm, at which time it is too late.